THE RADIATION FIELD IN PHOTOSPHERIC MODELS FOR EXTREME SUPERGIANTS

C. DE JAGER
The Astronomical Institute, Utrecht, Holland

and

L. NEVEN
Royal Belgian Observatory, Brussels, Belgium

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Abstract. On the basis of assumed photospheric temperature models for 36 extreme supergiants (log g-values of 1, 0.5 and 0; $T_e$ ranging from approx. 3700-33 000 K) photospheric fluxes $S(\lambda)$ were computed for 36 wavelengths ranging from 100 Å to 60 000 Å. The hot models are in perfect radiative equilibrium; the cooler show deviations up to 10%, sometimes even larger. Only in the relatively deep parts of the photospheres ($\tau_5 \gtrsim 1$) the radiation field at each geometrical level can be characterized by one unique radiation temperature; for smaller $\tau_5$-values there are large deviations from local thermal equilibrium. The influence of deviations from local thermodynamical equilibrium on the fluxes is briefly examined, and appears small but for the shortest wavelengths. In tables and graphs we give for these models $\pi F(\lambda)$-values, integrated fluxes, effective temperatures, colours $U$, $B$ and $V$, and the Balmer discontinuity $D$.

1. Introduction

Extreme supergiants (luminosity classification Ia or Ia-0) are known to have very small values for the effective acceleration of gravity $g_e$. Estimated effective $g$-values of the order of 1 or even smaller are occasionally mentioned in the astrophysical literature (see, e.g., Th. and J. Walraven, 1971; Wallerstein, 1973). Yet, no photospheric models of stars have so far been published for effective log $g$-values $\lesssim 1$. This fact is not surprising since first it is difficult to compute a photospheric model for a star with a small $g$-value: in view of the very large ratios between the scattering and absorption coefficients in the tenuous atmospheres of these stars, radiation transport may not be fully determining the temperature stratification; hence the usual radiative equilibrium models may not be suitable for such stars.

Secondly, the usual plan-parallel photosphere approximation might not be applicable because of the extension of supergiant photospheres as compared with the stellar radii.

A third problem is related to the uncertainty of computing $g_e$-values for a model with a given $g_{\text{Newton}}$-value. Offhand the most logical way to proceed seems to base the computations on an assumed value of the geometrical $g$-value ($g_\text{g}$), and to compute $g_e$ by adding the (negative) acceleration $g_{\text{rad}}$ due to radiation pressure. Then, however, there still remains the unknown contribution to $g$ by turbulence or by the stellar wind.
These latter contributions are in most cases unknown but they may be of the same order as $g_N + g_{\text{rad}}$, and therefore a straightforward computation of $g_e$ may be illusory. We therefore tried to escape at least from that difficulty by basing the computations for the various models on an assumed $g_e$-value, taken constant with height. The fact that the real $g_e$-function will instead show a $\tau$-dependency is accepted as an inevitable shortcoming of the computations. We think, though, that it will be a less serious defect to the models than the one resulting from computations based on an assumed $g_N$-value, in which the influence of turbulence and/or stellar winds is ignored.

On the basis of the philosophy outlined above, we have attempted to develop methods for computing the source functions $S(\tau_e)$ and radiation fluxes $\pi F(\lambda)$ for models with log $g$ = 0, 0.5, and 1.0, for assumed $T(\tau_e)$ relations. We did not yet pay much attention to derive very precise $T(\tau_e)$-relations because of the difficulties mentioned above. This, however, is not very harmful, since for photospheres with $\kappa_\lambda/\sigma_\lambda \approx 0$ the resulting $S(\tau_e)$ relation is largely independent of the assumed $T(\tau_e)$ relation, as will be shown further in this paper.

2. The Assumption of Plan-Parallel Atmospheric Layers

Throughout our investigation we assumed plan-parallel atmospheric layers, i.e., we assumed that the mean free path of a photon in the photosphere is small as compared to the stellar radius. We have to verify this assumption. The mean free path of a photon is of the order of the optical scale height $\theta$, defined by $dz = \theta \, d \log \tau$, with $z =$ geometrical depth, $\tau =$ optical depth. It was shown by Van Bueren (1972) that in most stellar photospheres, and for most wavelengths: $\theta \approx H$, the density scale height.

Hence, our assumption of plan-parallel layers reduces to the condition that

$$H < \delta R,$$

where $\delta$ is small, of the order 0.1 or 0.01. With $H = RT/\mu g_e$, and $R = (Gm/g)^{1/2}, g_e = \theta g$, condition (1) reduces to

$$(g_e)_{\text{lim}} = \frac{T^2}{\theta \delta^2 \mu R}.$$

For $g_e > (g_e)_{\text{lim}}$ the plan-parallel approximation is justified.

To elaborate condition (2) we take:

$$\begin{align*}
\mu &= 1.4 \quad \text{for} \quad T < 8000 \text{ K}, \\
\mu &= 1.0 \quad \text{for} \quad T = 8000 \text{ K}, \\
\mu &= 0.6 \quad \text{for} \quad T > 8000 \text{ K}.
\end{align*}$$

These data resulted from the model computations to be described later in this paper (Table II).